RADIOGRAPHIC MEASUREMENT OF VERTEBRAL HEART SIZE IN PREGNANT CATS AND CATS WITH UTERINE DISEASES

By

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ABSTRACT

An abstract of the research paper presented to the Faculty of Veterinary Medicine, Universiti Malaysia Kelantan, in partial requirement of the course DVT 55204 – Research Project.

The Vertebral Heart Size (VHS) is a critical, standardized radiographic tool for detecting cardiomegaly in small animals. The established VHS range (6.7–8.1 V) for healthy cats may not adequately represent the physiological cardiac adaptations during pregnancy or pathological conditions of the uterus. This study aimed to determine the mean VHS in pregnant cats and cats with uterine diseases. By comparing these values to the published normal reference range, we can enhance diagnostic accuracy for these specific patients. A retrospective cross-sectional study was conducted using medical records and lateral thoracic radiographs from a total of 75 female cats (n=52 pregnant, n=23 with uterine diseases) from the year of 2020 to 2024. VHS was measured according to the standard of the Lister and Buchanan method (2000). Statistical analysis revealed a highly significant increase in VHS in both groups compared to the normal mean of 7.5 V ($p < 0.001$ for both). Pregnant cats exhibited a mean VHS of 8.4 ± 0.5 V, with a range of 8.2 V to 8.5 V. Cats with uterine diseases (including pyometra, fetal death, and endometrial hyperplasia) showed an estimated median VHS of 8.0 V (95% CI: 7.8–8.2 V). The difference in VHS between the pregnant cats and cats with uterine diseases was not statistically significant ($p = 0.085$). The findings suggest that pregnancy-induced hemodynamic changes, such as increased cardiac output and cardiac hypertrophy, lead to an increase in VHS. Similarly, the elevation in VHS in cats with uterine diseases is likely caused by the systemic inflammatory responses (e.g., SIRS/sepsis in pyometra animals). This study shows that the conventional feline VHS reference range should be used with care for pregnant queens and cats with uterine pathology. A VHS of up to 8.5 V should be considered within the normal physiological range for pregnant cats, supporting more accurate radiographic interpretation in clinical practice.

Keywords: Vertebral Heart Size, VHS, cat, pregnancy, pyometra, cardiomegaly, uterine diseases, radiography.

ABSTRAK

Abstrak daripada kertas penyelidikan yang dibentangkan kepada Fakulti Perubatan Veterinar, Universiti Malaysia Kelantan, sebagai keperluan sebahagian daripada kursus DVT 55204 – Projek Penyelidikan

Saiz Jantung Vertebra (Vertebral Heart Size, VHS) ialah cara piawaian radiografik yang penting untuk mengesan kardiomegali dalam haiwan kecil. Julat VHS yang telah ditetapkan (6.7–8.1 V) bagi kucing sihat mungkin tidak menggambarkan sepenuhnya adaptasi fisiologi jantung semasa bunting atau keadaan patologi uterus. Kajian ini bertujuan untuk menentukan purata VHS dalam kucing bunting dan kucing dengan kelainan uterus. Dengan membandingkan nilai ini dengan julat rujukan normal yang diterbitkan, ketepatan diagnostik bagi pesakit khusus ini dapat dipertingkatkan. Kajian retrospektif keratan rentas ini telah dijalankan menggunakan rekod perubatan dan radiograf toraks lateral melibatkan sejumlah 75 kucing betina (n=52 bunting, n=23 dengan kelainan uterus) dari tahun 2020 hingga 2024. VHS diukur mengikut piawaian kaedah Lister dan Buchanan (2000). Analisis statistik menunjukkan peningkatan VHS yang sangat signifikan dalam kedua-dua kumpulan berbanding purata normal 7.5 V ($p < 0.001$ bagi kedua-duanya). Kucing bunting menunjukkan purata VHS 8.4 ± 0.5 V, dengan julat antara 8.2 V hingga 8.5 V. Kucing dengan kelainan uterus (termasuk pyometra, kematian fetus, dan hiperplasia endometrium) menunjukkan nilai median VHS dianggarkan sebanyak 8.0 V (95% CI: 7.8–8.2 V). Perbezaan VHS antara kucing bunting dan kucing dengan kelainan uterus tidak signifikan secara statistik ($p = 0.085$). Penemuan ini berkemungkinan disebabkan oleh perubahan hemodinamik akibat kebuntingan, di mana peningkatan output jantung diperlukan untuk mencapai keperluan fetus dalam uterus, menyumbang kepada hipertrofi jantung dan peningkatan VHS. Kajian ini menunjukkan bahawa julat rujukan VHS konvensional untuk kucing perlu digunakan dengan berhati-hati terhadap kucing bunting dan kucing dengan patologi uterus. VHS sehingga 8.5 V harus dianggap dalam julat fisiologi normal bagi kucing bunting, seterusnya menyokong interpretasi radiografi yang lebih tepat dalam amalan klinikal.

Kata kunci: Saiz Jantung Vertebra, VHS, kucing, bunting, pyometra, kardiomegali, kelainan uterus, radiografi.

CERTIFICATION

This is to certify that we have read this research paper entitled 'Radiographic Measurement of Vertebral Heart Size in Pregnant Cats and Cats with Uterine Diseases' by Ng Qi Xun, and in our opinion, it is satisfactory in terms of scope, quality, and presentation as partial fulfillment of the requirements for the course DVT 55204 – Research Project.

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LIST OF ABBREVIATIONS

VHS	Vertebral heart size/score
V	Vertebrae
VLAS	Vertebral left atrium score
TWM	Thoracic width measurement
CO	Cardiac output
PPCM	Peripartum cardiomyopathy
TNF-α	Tumor necrosis factor-alpha
NF-κB P65	Nuclear factor-kappa-B p65
UMK	Universiti Malaysia Kelantan
HPVUMK	Hospital Pengajar Perubatan Universiti Malaysia Kelantan
SPSS	Statistical Package for the Social Sciences
SD	Standard deviation
CI	Confidence interval
IQR	Interquartile range
N or n	Number of samples
NT-proBNP	N-terminal pro B-type natriuretic peptide
SIRS	Systemic inflammatory response syndrome
CRP	C-reactive protein
IL-6	Interleukin-6

LIST OF SYMBOLS

%	Percentage
<	Less than
=	Equal to

CHAPTER 1

1.0 INTRODUCTION

Radiographic assessment of the vertebral heart size (VHS) is a widely used and standardized method in small animal practice, especially in cats and dogs. It plays an important role in detecting and monitoring the progression of cardiac disease. With the aid of a well-established, species-specific reference range of VHS, an enlarged cardiac silhouette on radiographs can indicate pathological changes within the heart. It may provide an early indication of cardiomegaly, even in the absence of an echocardiogram, which remains the gold standard for cardiac evaluation. Serial VHS measurements are valuable for monitoring disease progression.

On the other hand, significant physiological changes occur in animals during pregnancy, particularly within the cardiovascular system. Pregnancy burdens the cardiovascular system, leading to an increase in cardiac output to support the greater metabolic demands that sustain the needs of both the mother and the developing fetus. The heart undergoes structural and functional adaptations to compensate for this increased workload. A queen was diagnosed with congestive heart failure during her late-term pregnancy; however, the symptoms resolved after cesarean section, suggesting the association of pregnancy and cardiovascular strain (Stoneham *et al*., 2006).

Although normal VHS values are well established for non-pregnant cats, limited information exists regarding how pregnancy may alter heart size as measured by this method. Given the circulatory adaptations during gestation, it is reasonable to expect that VHS values in pregnant queens may differ from those of non-pregnant cats.

Therefore, this study aims to evaluate VHS measurements in pregnant cats and cats with uterine diseases to determine whether pregnancy and pathological changes in the uterus induce measurable changes in cardiac size. Gaining insight into these variations may improve the accuracy of radiographic cardiac evaluations in queens and ensure better veterinary diagnostic practices.

1.1 PROBLEM STATEMENT

During pregnancy, significant physiological changes occur in the body, including increased blood volume and cardiac output to accommodate the demands of maternal and fetal metabolic activities, particularly in mammalian species (Rosenfeld, 2019). It is highly suggestive that these could influence heart size, as mentioned by Blanco et al. in 2020, there is a presence of eccentric cardiac hypertrophy during pregnancy, which may, in turn, affect the VHS measurement. However, there is currently a lack of published data specifically evaluating the impact of pregnancy on VHS measurement in cats. No established research and data support that pregnant cats have a normal heart size, nor do their VHS fall in the average VHS range of non-pregnant cats, which is 6.7 to 8.1 V. Furthermore, no standardized VHS reference values exist for pregnant cats or those with uterine diseases such as pyometra, endometrial hyperplasia, endometriosis and other conditions which may alter the cardiac output distribution and cause enlargement of the heart in such conditions. This lack of data causes a diagnostic challenge for veterinarians interpreting thoracic radiographs in these populations, as deviations in VHS may be misinterpreted without considering gestational or pathological influences. More targeted research is needed to determine whether pregnancy significantly affects cardiac silhouette size in felines and to establish reliable reference ranges for use in veterinary clinical practice.

1.2 RESEARCH QUESTIONS

1. What is the mean VHS value and range in pregnant cats and cats with uterine diseases?
2. Is there a difference in the VHS value between pregnant and non-pregnant cats?
3. Is there a difference in the VHS value between healthy cats and cats with uterine diseases?
4. Is there a difference in the VHS value between pregnant cats and cats with uterine diseases?

1.3 RESEARCH OBJECTIVES

1. To determine the mean VHS value in pregnant cats and cats with uterine diseases.
2. To compare the mean VHS value in pregnant cats and cats with uterine diseases with the normal cats.

1.4 RESEARCH HYPOTHESIS

1. Null hypothesis (H_0): VHS in pregnant cats and cats with uterine diseases is similar compared to non-pregnant healthy cats.
2. Alternative hypothesis(H_1): VHS in pregnant cats and cats with uterine diseases is higher compared to non-pregnant healthy cats.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 OVERVIEW OF APPLICATION OF VERTEBRAL HEART SCORE IN SMALL ANIMAL PRACTICE

A thoracic radiograph is one of the most used diagnostic tools for veterinary practitioners to evaluate the heart size of cats and dogs with suspected heart diseases, particularly with the presence of cardiomegaly (Guglielmini & Diana, 2015). Vertebral heart score (VHS) is an objective radiographic measurement of cardiac silhouette used in small animals, including cats and dogs, despite other imaging modalities, such as echocardiography (Castaneda & Estrada, 2022; Fox-Alvarez & Estrada, 2016). It is the easiest and standard way to assess the heart size of animals, by using the vertebrae as the measuring unit. It involves measuring the long and short axes of the cardiac silhouette on the thoracic radiograph and comparing these dimensions to the length of thoracic vertebrae, starting from the fourth thoracic vertebrae. The published range for normal VHS in cats is 6.7 to 8.1 on lateral radiographs, which is widely applied by veterinary practitioners worldwide (Lister & Buchanan, 2000). Despite detecting the enlargement of the heart size in a thoracic radiograph, it is also a practical and objective tool that allows the documentation and monitoring of the progression of the heart size over the treatment period. VHS is also a valuable tool to differentiate respiratory distress in cats caused by cardiac diseases from noncardiac conditions in emergencies, where other diagnostic imaging is not available (Sleeper *et al.*, 2013).

In addition to VHS, other parameters were used simultaneously to assess the radiographic heart size, including vertebral left atrium score (VLAS) and thoracic width measurement (TWM). However, radiographically measured VHS, VLAS, and TWM may each reflect distinct and independent aspects of cardiac morphology and condition (Özdil *et al.,* 2025). Considering applications of multiple radiographic measurements improves the accuracy of cardiac assessment while maximising the diagnostic value of each radiograph obtained.

In emergency situations, VHS can help differentiate between cardiac and non-cardiac causes of respiratory distress in cats (Brennan *et al.,* 2022). A VHS greater than 8.0 vertebrae is indicative of heart disease, while a VHS above 9.3 vertebrae is specific for heart disease (Sleeper *et al.,* 2013). This makes VHS a valuable tool in emergency settings where rapid decision-making is crucial.

As the measurement of VHS involves the vertebrae of the animal, hence, abnormal thoracic vertebrae may interfere with the value of VHS when using the conventional VHS method. Applied VHS was used to obtain a more accurate value and measurement with reliable and maximal diagnostic value; however, the application of the applied VHS technique in different cat breeds requires further research (Rungpupradit & Sutthigran, 2020).

2.2 CARDIOVASCULAR CHANGES IN PREGNANT MAMMALS

During pregnancy, mammals undergo cardiovascular modification and adaptation to support fetal development, where the ultimate mechanism involved is increased cardiac output to the gravid uterus (Klein & Pich, 2003; Itskovitz-Eldor & Thaler, 2005). The changes include elevated cardiac output, increased plasma volume, a marked decrease in peripheral vascular resistance, and a prominent increase in uteroplacental blood flow (Klein & Pich, 2003; Oslo *et al.*, 2019).

Schrier et al. (1994) and De Almeida et al. (2017) proposed that plasma volume and cardiac output have increased markedly, even by up to 50% during pregnancy. It was hypothesized that the pregnancy-related hormones, such as estrogen and progesterone, cause an increase in nitric oxide that leads to an increase in cardiac output and renal sodium and water retention.

Research conducted by the Department of Obstetrics and Gynecology at the University of Colorado Health Science Center in 2004 revealed cardiovascular changes during normal pregnancy. A growing fetus requires an approximately tenfold increase in uterine blood flow, resulting in 17% of cardiac output during pregnancy, which indicates a maternal hemodynamic response. As early as 5 weeks of gestation, the stroke volume and heart rate will increase, leading to an increase in cardiac output. During labour, cardiac output increases by 12% to 31% during the first stage of parturition and may increase up to 49% in the second stage of parturition.

In pregnant animals, the distribution of cardiac output shifts progressively throughout the gestation period. A study comparing cardiac output and organ blood flows in pregnant and non-pregnant ewes reported no significant change in systemic blood pressure during pregnancy; however, cardiac output per kilogram of body weight and heart rate increased markedly (Rosenfeld *et al.*, 2019). When the ewes approached term, the blood flow to the uterus and mammary glands accounted for approximately 18% of the cardiac output, while perfusion to several non-reproductive tissues also increased as gestation advanced.

According to Blanco et al. (2020), both cardiac structure and function in pregnant queens undergo significant changes, particularly during the second half of gestation, which includes increases in interventricular septal thickness, left ventricular internal diameter, left ventricular free wall thickness, fractional shortening, stroke volume, cardiac output, heart rate, and peak velocities of early and late diastolic transmitral flow. These increased cardiac parameters are highly likely to occur in response to the hemodynamic changes associated with pregnancy. Eccentric cardiac hypertrophy was also observed in pregnant queens, consistent with patterns described in pregnant humans and bitches.

In other animals, such as pigs, pregnancy alters heart rate variability, specifically increasing the heart rate in primiparous pigs (Marchant-Forde and Marchant-Forde, 2004). In mice, maternal blood flow to the placenta varies with litter size and is reduced in placentas positioned centrally within the uterine horn. In addition, the presence of a dual arterial supply is an evolutionarily conserved feature in mammals that carry a single offspring, including primates (Raz *et al.,* 2012). There is significant involvement of endothelial nitric oxide in cardiac remodeling, which helps elevate stroke volume in late gestation (Kulandavelu *et al.*, 2006).

2.3 CARDIOVASCULAR DISEASE ASSOCIATED WITH PREGNANCY

A case report stated that a 4-year-old Himalayan queen was diagnosed with biventricular congestive heart failure, accompanied by pleural effusion and pulmonary edema, during its late pregnancy (Stoneham *et al.,* 2006). The queen with a 63-day post-breeding pregnancy was presented with tachypnea, tachycardia, and hypothermia; the radiograph revealed pregnancy of 4 fetuses as well as cardiomegaly. Echocardiography was done and revealed a moderate left atrial enlargement, mitral regurgitation, and moderate right heart enlargement; hence, diagnosed with congestive heart failure. Considering the survivability of the queen and kitten, en bloc ovariohysterectomy and cesarean section were done. The queen's clinical signs improved significantly 12 hours after the operation. 9 months after surgery, echocardiography was performed, and the heart condition had improved to an acceptable state where medical therapy was not required. The author emphasized that the pregnancy may be the stressor that induced the congestive heart failure in a cat with cardiomyopathy, suggestive of being similar to peripartum cardiomyopathy (PPCM) in human medicine. Hence, it was suggested that the congestive heart failure was secondary to the pregnancy that induced the cardiovascular volume overload.

In human medicine, peripartum cardiomyopathy (PPCM) is one of the fatal idiopathic cardiac failures that develops during pregnancy in women without a history of cardiac disease. The development of PPCM is related to hormonal fluctuations, angiogenic imbalance, and genetic factors, with pre-eclampsia as a predisposing factor (Hoes *et al*., 2022). PPCM is a significant health concern in human medicine due to its potential severity and impact on maternal health. Research and study in PPCM and cardiovascular changes in pregnant individuals are essential for early diagnosis, effective treatment, and improved prognosis for affected mothers.

2.4 BREED ASSOCIATION WITH THE RADIOGRAPHIC MEASUREMENT OF HEART SIZE IN CATS

According to Oliveira et al. (2014), Maine Coon cats have a statistically significantly higher VHS score compared to non-Maine Coon cats, most likely due to their giant breed size. Sixty-three Maine Coon cats were thoroughly examined for their health conditions, and chest radiographs were taken. The VHS of Maine Coon cats obtained at the end of the research was 7.61±0.34 vertebrae with a minimum of 6.9 and a maximum of 8.5 vertebrae, which was statistically proven to be higher than the VHS of non-Maine Coon cats.

In addition, it is suggestive that the brachycephalic breeds may have a larger VHS; for example, Persian cats have an average VHS of 8.16 vertebrae compared to the general average of 7.5 thoracic vertebrae in other breeds (Castaneda & Estrada, 2022). This suggests that breed-specific anatomical differences can influence radiographic heart measurements. In a study of stray cats, the mean VHS values were slightly smaller than those reported for mixed populations, indicating potential breed-related differences (Ghadiri *et al.,* 2008).

2.5 UTERINE DISEASES IN RELATION TO CARDIOVASCULAR CONDITIONS

Pyometra is a severe uterine infection characterized by the accumulation of pus in the uterine lumen, leading to systemic inflammatory responses and potential sepsis (Zhelavskyi *et al.,* 2020). A study was conducted to compare healthy queens and those with pyometra, assessing uterine blood flow, oxidative stress markers, and histopathological changes. Doppler ultrasonography found that queens with pyometra had significantly increased uterine diameter and thickness but reduced blood flow velocity. Biochemically, they exhibited lower total antioxidant capacity and albumin levels, accompanied by higher malondialdehyde levels, suggesting oxidative stress. Histopathology revealed fibrosis and inflammation, while immunohistochemistry showed increased expression of TNF-α and NF-κB p65 in pyometra cases. These findings suggest that Doppler ultrasound and oxidative stress markers can aid in the diagnosis and understanding of feline pyometra (Abdelnaby *et al.*, 2024).

A 6-year-old intact female Ragdoll cat presented with lethargy, anorexia, and vaginal discharge. Imaging revealed pleural effusion, a globoid heart silhouette, and pericardial effusion (Majoy *et al.*, 2012). Pericardiocentesis showed septic pericarditis with Gram-negative rods, and ultrasound identified uterine diseases suggestive of pyometra. After stabilization, the cat underwent ovariohysterectomy and partial pericardiectomy. Histopathology confirmed pyometra and septic pericarditis, with *Escherichia coli* isolated from both the uterine and pericardial fluids, sharing identical antimicrobial sensitivities.

According to Pugliese *et al.* (2020), cardiac arrhythmias are common in bitches with closed cervix pyometra. The most frequent abnormalities were sinus tachycardia (56.4%), ventricular premature complexes (23%), and low wave amplitude (43.5%). These ECG changes are likely associated with myocardial damage, sepsis, or metabolic disturbances linked to pyometra.

CHAPTER 3

3.0 METHODOLOGY

3.1 STUDY AREA

This research was conducted at the Veterinary Medicine Teaching Hospital of Universiti Malaysia Kelantan (HPVUMK) in Bachok, Kelantan. Analysis of the case, radiographic imaging, and VHS measurements were conducted at the Faculty of Veterinary Medicine of UMK.

3.2 STUDY DESIGN

This research study used a retrospective cross-sectional study where medical records and radiographs, that fulfilled inclusion criteria, from the year of 2020 to 2024 were retrieved from HPVUMK.

3.3 STUDY POPULATION

The study population involved in this research study is female cats of various ages, breeds, and sizes with a diagnosis of pregnancy or uterine diseases, such as pyometra, fetal mummification, fetal maceration, dystocia, and endometrial hyperplasia.

3.4 SELECTION CRITERIA

3.4.1 INCLUSION CRITERIA

1. Female cats with a confirmed diagnosis of pregnancy/pyometra/endometrial hyperplasia/fetal maceration/fetal mummification, or any uterine disease
2. Have a thoracic radiograph (lateral view) or catogram with proper positioning of the chest region that is suitable for vertebral heart size measurement (e.g., superimposed of ribs in lateral view)
3. Cats without clinical evidence of cardiac or pulmonary disease
4. The thoracic radiograph shows no evidence of respiratory diseases.

3.4.2 EXCLUSION CRITERIA

1. Cats with a previous history of cardiac diseases
2. Radiographs that are not properly positioned to the degree that it may affect the cardiac silhouette position
3. Cats with vertebral abnormalities were excluded, as this may affect the VHS, since this study is using the conventional VHS instead of the applied VHS, which can adapt to the abnormal vertebrae in special individuals.

3.5 SAMPLING METHOD AND PROCEDURE

3.5.1 DATA COLLECTION

The clinical records of the HPVUMK were reviewed, covering the period from the year of 2020 to 2024. Patient data and radiographic data were collected based on the reasons for visit and clinical diagnoses recorded in the hospital database. Cats with reproductive-related visit reasons, such as pregnancy diagnosis, vaginal discharge, dystocia, abortion, difficulty during parturition, and postpartum check-ups, were identified as relevant keywords. In addition, radiographs of cats diagnosed with the mentioned reproductive conditions, including pregnancy, pyometra, fetal death, fetal maceration, fetal mummification, endometrial hyperplasia, endometriosis, and other female reproductive tract disorders, were retrieved for analysis.

These cases obtained were grouped into two groups according to the diagnosis of the medical record. The two groups are the group of pregnant cats and the group of cats with uterine diseases. The group of cats with uterine diseases was the cats diagnosed with pyometra, dystocia, fetal death, fetal maceration, fetal mummification, endometrial hyperplasia, and endometriosis.

3.5.2 RADIOGRAPH AND VERTEBRAL HEART SIZE MEASUREMENT

The radiographs collected were analyzed to ensure the cats were squarely positioned, with bilateral ribs superimposed. Those radiographs that fulfilled the characteristics above were selected for VHS measurements.

The vertebral heart size measurement used in this study is based on the guidelines established by Lister and Buchanan (2000).

As described by Lister and Buchanan (2000), in the lateral view of the thoracic radiograph, to obtain the VHS measurement, the cardiac long axis was first drawn from the cardiac apex to the heart base, located at the intersection of the ventral tracheal margin and the most ventral apical vein (lobar vein) cranial to the tracheal bifurcation (carina). Next, the cardiac short axis was drawn perpendicular to the long axis at the point of greatest cardiac width, usually where the cardiac silhouette intersects the caudal vena cava. Both the long and short axes were then transposed onto the vertebral column, aligned parallel to the spine, starting from the cranial border of the fourth thoracic vertebrae. The number of vertebrae encompassed by each axis was counted, and the VHS was determined by summing these two measurements, expressed in vertebral units (V) (Figure 1).

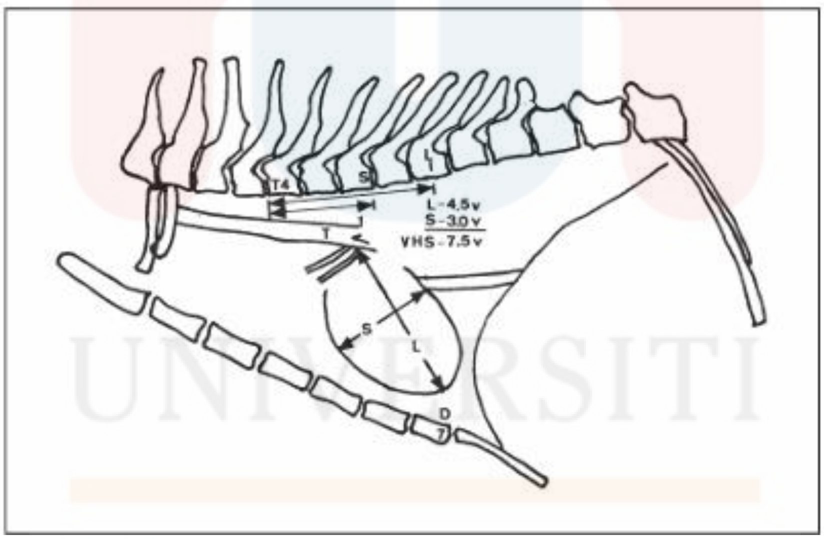

Figure 1: Schematic diagram of VHS measurement on a radiograph. The diagram above was adapted from Litster AL, Buchanan JW (2000), which illustrated the lateral view of a cat's thorax. The long-axis (L) and the short-axis (S) were transposed onto the vertebral column, starting from the fourth thoracic vertebral column. The number of vertebral columns corresponding to the L and S was added to obtain the VHS.

3.6 DATA ANALYSIS

The data were descriptively analyzed, and data normality was tested using the Statistical Package for the Social Sciences (SPSS).

The normality of VHS values was first evaluated using the Shapiro–Wilk test. For the group of pregnant cats, the VHS values were compared with the published normal mean of 7.5 V by using a one-sample t-test, as the data were normally distributed. In contrast, the VHS data from cats with uterine diseases were not normally distributed; hence, they were compared with the reference VHS value of 7.5 V using the One-Sample Wilcoxon Signed-Rank Test. To obtain a VHS median of the group of cats with uterine diseases, with 95% CI, a bootstrapping procedure was carried out. A Mann–Whitney U test was used to compare VHS values between pregnant cats and cats with uterine diseases. A significance level of $p < 0.05$ was considered statistically significant.

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CHAPTER 4

4.0 RESULT AND DISCUSSION

4.1 RESULTS

Based on the reason for the visit of female cats to HPVUMK, a total of 252 cases, ranging from the years of 2020 to 2024, were selected, with 182 of them having radiography done during the visit. After filtering the radiograph images, 107 radiographs were excluded due to the absence of an adequate area of interest, making it impossible to perform VHS measurement. Additionally, some radiographs were excluded due to improper positioning. Thus, 75 lateral-view, squarely positioned radiographs were selected for VHS measurement. Out of 75 selected female cats, 52 were pregnant, and 23 had uterine diseases.

Out of 23 cases of cats that were grouped under uterine diseases, 16 cases were diagnosed with pyometra, including closed and open forms of pyometra. 6 cases were abortions, and 1 case was cystic endometrial hyperplasia accompanied by hydrometra (Figure 2).

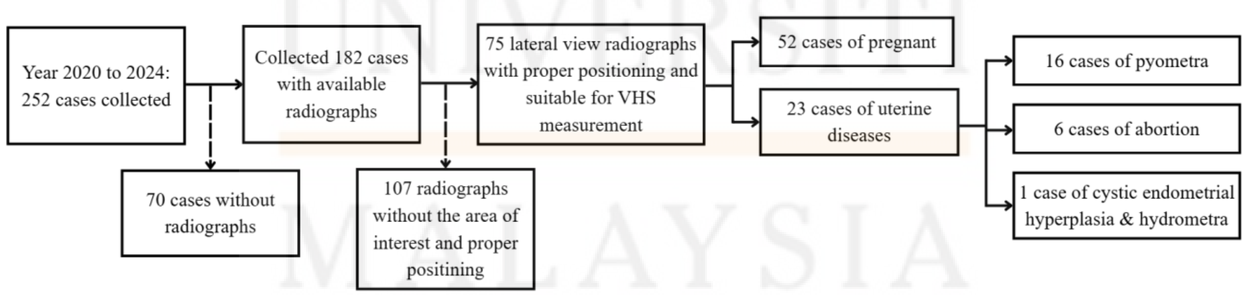

Figure 2: Selection of cases with relevant diagnosis with suitable radiograph for VHS measurement. Dotted-line arrows represent excluded cases.

4.1.1 COMPARISON OF THE GROUP OF PREGNANT CATS WITH THE NORMAL MEAN OF VHS

The one-sample t-test revealed a statistically significant increase in VHS among pregnant cats when compared with the published normal value of 7.5 V. Pregnant cats exhibited a mean VHS of 8.4 ± 0.5 V, exceeding the reference mean by 0.87 V. This difference was highly significant ($p < 0.001$), suggesting that pregnancy is associated with an increased vertebral heart size measurement. The VHS range for pregnant cats is 8.2 V to 8.5 V (Table 4.1).

Table 4.1: VHS between the group of pregnant cats with the normal mean of VHS.

Variables	Mean (SD)		Mean difference (95% CI)	95% CI for Mean		P value
	Pregnant cat	Normal VHS		Lower Bound	Upper Bound	
VHS (V)	8.4 (0.5)	7.5 (0.3) *	0.87	8.2	8.5	<0.001

*Adopted from Buchanan and Lister (2000).

4.1.2 COMPARISON OF THE GROUP OF CATS WITH UTERINE DISEASES WITH THE NORMAL MEAN OF VHS

The one-sample Wilcoxon signed-rank test demonstrated a significant difference between the VHS values of cats with uterine diseases and the published normal VHS value of 7.5 V ($P < 0.001$). This suggests that the median VHS in this group differs significantly from the reference standard.

Table 4.2: VHS between the group of cats with uterine diseases with the normal mean of VHS

Group	N	Test value (V)	P value
Uterine abnormality	23	7.5 *	<0.001

*Adopted from Buchanan and Lister (2000).

The estimated median VHS for the group of cats with uterine diseases was 8.0 V. With 95% confidence, the median VHS of the cats with uterine diseases was located between 7.8 V to 8.2 V.

4.1.3 COMPARISON OF THE GROUP OF PREGNANT CATS WITH THE GROUP OF CATS WITH UTERINE DISEASES

The Mann–Whitney U test showed no statistically significant difference in VHS between pregnant cats and those with uterine diseases (P = 0.085).

Table 4.3: VHS between the groups of pregnant cats and cats with uterine diseases.

Variables	Pregnant cat (n = 52) Median (IQR)	Cat with uterine diseases (n = 23) Median (IQR)	Z statistics	P value
VHS (V)	8.5 (0.8)	8.0 (1.2)	-1.72	0.085

CHAPTER 5

5.0 DISCUSSION

A significant difference was observed between the VHS values of pregnant cats and healthy, non-pregnant cats, with means of 8.4 ± 0.5 V and 7.5 ± 0.3 V, respectively, indicating an increase of approximately 0.9 ± 0.2 V. This suggests that notable cardiovascular changes occur during pregnancy. Physiologically, these findings are consistent with the adaptive responses of the maternal cardiovascular system to increased demands on cardiac output.

In viviparous mammals, the uterus serves as the primary site of fetal growth and development, and the fetus requires continuous nutritional and metabolic support throughout gestation until parturition. The increased metabolic demands of the developing fetus cause an additional workload on the maternal heart, leading to cardiac remodeling (Vargas *et al.,* 2023; Lan *et al.,* 2025). Structural and hemodynamic changes occur during pregnancy, particularly in cardiac output and systemic vascular resistance (Sanghavi & Rutherford, 2014). According to the Frank–Starling mechanism, cardiac output increases through an increase in both heart rate and stroke volume (Delicce & Makaryus, 2023). In response to this increased workload, the heart undergoes hypertrophy, which helps maintain adequate cardiac output (Kulandavelu *et al., 2006*). This hypertrophic response is generally considered an adaptive mechanism; however, inadequate adaptation may progress to cardiac dysfunction (Redaktion, 2013). Pregnancy-associated cardiac disease, such as congestive heart failure, has been reported where the queen was diagnosed with bilateral congestive heart failure during its pregnancy, and the cardiac condition was stable 9 months after an en bloc ovariohysterectomy was done, suggesting pregnancy-associated cardiomyopathy (Stoneham *et al.*, 2006).

In domestic short-hair cat, there are detectable changes in the cardiovascular system during the second half of gestation, including an increase in interventricular septal thickness, left ventricular internal dimension and its free wall, fractional shortening, stroke volume, and cardiac output (Blanco *et al.,* 2020). In general, ossification of fetal bones in cats begins around day 38 of gestation and is radiographically visible between days 40 and 45, corresponding to the second trimester (Davidson, 2025). The radiographs used in this case were noted to have visible fetal structures; hence, the individual included in this study was at least second trimester, corresponding to the statement mentioned earlier. Therefore, pregnancy-associated increases in heart size are likely observable from the second trimester onward, with radiographic changes becoming detectable as fetal development progresses. This may potentially help to determine the possible cardiac changes that are associated with pregnancy or changed due to underlying cardiac disease.

On the other hand, cats with uterine diseases demonstrated significantly higher VHS values compared with healthy cats, suggesting that pathological uterine conditions may contribute to notable cardiovascular changes. For the group of cats with uterine diseases, systemic inflammation was highly likely, leading to an increase in heart size. As mentioned, pyometra was included within this category. Systemic complications are frequently observed in affected animals, which can progress to systemic inflammatory response syndrome (SIRS), sepsis, and endotoxic shock; these conditions ultimately lead to multi-organ failure (Griffon & Hamaide, 2016). When a systemic inflammatory response occurs, levels of inflammatory markers such as C-reactive protein (CRP), tumor necrosis factor-alpha (TNF-α), and interleukin-6 (IL-6) are markedly increased (Karabulut *et al.,* 2016). These inflammatory cytokines and oxidative stress can contribute to myocardial inflammation and remodeling, potentially leading to cardiomegaly (Fonfara *et al.,* 2021). Research conducted by Liu et al. (2018) suggests an association between inflammation and heart disease, where biomarkers such as NT-proBNP and acute-phase proteins increase in cats with congestive heart failure resulting from systemic inflammation. A cat with pyometra may exhibit an increase in cardiac troponin I, indicating damage to both cardiac cells and the cardiac muscle (Safak *et al., 2025*).

For cystic endometrial hyperplasia accompanied by hydrometra, only one case is involved in this study, and the individual has a normal VHS value, within the normal VHS range of a normal non-pregnant cat. Therefore, the association between cystic endometrial hyperplasia and cardiomegaly remains inconclusive in this study and requires further investigation, as no available research papers mention this association. However, in human medicine, there are small associations between endometriosis and cardiovascular disease instead (Marchandot *et al.,* 2022).

This study has several limitations that should be acknowledged. First, the cats included were not examined for cardiac status throughout their pregnancy, nor at the time the radiographs were taken. As a result, there was no direct confirmation of potential structural changes in the heart, and mild cardiac disease or congenital cardiac abnormality may have gone undetected. In Kelantan, routine annual health screenings, including radiography and echocardiography, are not commonly practiced among pet owners, leading to incomplete medical histories and an increased possibility of underdiagnosed cardiac conditions.

Besides, breed was not used as an exclusion criterion due to the limited sample size. Ideally, breeds known to have larger normal VHS values, such as Maine Coons and Persians, should be excluded to avoid confounding effects. However, aside from the mentioned reason, Maine Coons are uncommon in Kelantan, which reduces the likelihood of significant breed-related bias in this dataset that may have been induced by such a breed. There is also a big difference in the sample size between the pregnant group and the group with uterine diseases; hence, further investigation with a more homogenous sample size would be helpful in elucidating any relationship or association between the groups.

Additionally, only the lateral radiographic view was used for VHS assessment. While this aligns with common practice in small animal radiography, the use of a single view may limit the detection of subtle changes that could have been better evaluated in addition to ventrodorsal or dorsoventral views.

Future studies should consider obtaining radiographs at multiple stages throughout gestation to document the trend of VHS changes as pregnancy progresses. Ideally, radiographs should also be taken before pregnancy, immediately after parturition, and repeated several months to years later to determine whether VHS returns to pre-pregnancy values, as pregnancy-induced hypertrophy is reversible one week postpartum in mice. Further research should also be conducted in felines (Kaissar *et al., 2026*). This repeated radiography should also be applied to cats with uterine pathology, at the stage before and after intervention was done, as well as several months to years later, post-intervention. Logically, an increased number of fetuses will increase the metabolic demand, leading to an increase in cardiac output. Thus, future studies of the association of the number of litters with the maternal cardiovascular changes are needed.

Future research could further integrate other diagnostic indicators of cardiac health, including NT-proBNP, cardiac troponins, and blood pressure measurements, to better understand the cardiovascular physiology of pregnant cats and those with uterine pathology.

CHAPTER 6

6.0 CONCLUSION AND RECOMMENDATION

This study successfully determined the Vertebral Heart Size (VHS) in two feline populations: pregnant cats and cats diagnosed with uterine diseases. The research confirmed the hypothesis that both conditions are associated with a significant increase in VHS compared to the established normal reference range for healthy, non-pregnant cats (6.7–8.1 V, with a mean of 7.5 V).

Specifically, the mean VHS for pregnant cats was determined to be 8.4 ± 0.5 V (range 8.2 V to 8.5 V). This significant increase ($p < 0.001$) is strongly suggestive of the physiological adaptations of the maternal cardiovascular system, which undergoes volume overload and eccentric cardiac hypertrophy to support the increase in cardiac output required for fetal development.

Furthermore, cats with uterine diseases exhibited an estimated median VHS of 8.0 V ($p < 0.001$). This finding suggests that pathological changes in the uterus, such as systemic inflammation, sepsis, and metabolic disturbances associated with conditions like pyometra, place a substantial acute workload on the heart, resulting in detectable radiographic enlargement.

Finally, the study found no statistically significant difference in VHS values between the group of pregnant cats and the group of cats with uterine diseases ($p = 0.085$). This observation indicates that the degree of cardiovascular strain, as reflected by VHS, is comparable between the high-demand physiological state of late-stage pregnancy and the systemic pathological state induced by uterine disease.

In conclusion, this research provides vital clinical data demonstrating that the standard VHS reference range should be applied with care to pregnant cats or those with uterine pathology. The findings show a higher physiological reference range for pregnant queens (up to 8.5 V) to avoid the misdiagnosis of cardiomegaly in otherwise healthy, gestating animals. However, if cardiovascular disease is suspected, a thorough examination should be done to ensure the health of the cats.

Future studies should adopt a prospective and longitudinal design with comprehensive cardiac evaluations, including echocardiography and clinical assessments, to differentiate pregnancy- and disease-associated cardiac changes in cats. Using balanced sample sizes, breed-based stratification, multiple radiographic views, and serial imaging pre-, peri-, and post-partum would strengthen data reliability. Incorporating additional cardiovascular biomarkers, such as NT-proBNP, cardiac troponins, and blood pressure measurements, would further enhance the accuracy of diagnosis and improve understanding of feline cardiovascular adaptations.

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